Early Student Support for a Process Study of Oceanic Responses to Typhoons

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LONG-TERM GOALS

Our long-term scientific goals are to understand the upper ocean dynamics, to understand the coupling between the ocean and atmosphere via air–sea fluxes, and to quantify the mechanisms of air–sea interactions. Our ultimate goal is to help develop improved parameterizations of air–sea fluxes in ocean–atmosphere models and parameterizations of small-scale processes in the upper ocean and the stratified interior.

OBJECTIVES

Tropical cyclones derive energy from the ocean via air–sea fluxes. Oceanic heat content in the mixed layer and the air–sea enthalpy flux play important roles in determining the storm's maximum potential intensity, structure, energy, trajectory, and dynamic evolution. The most energetic oceanic responses to tropical cyclone forcing are surface waves, wind-driven currents, shear and turbulence, and inertial currents. Quantifying the effect of these oceanic processes on air–sea fluxes during tropical cyclone passage will aid understanding of storm dynamics and structure. The ocean's recovery after tropical cyclone passage depends upon small- and meso-scale oceanic processes in the storm's wake region. These processes are the least understood primarily because of the paucity of direct field observations under passing tropical cyclones; as a consequence, there are large uncertainties in air–sea flux parameterizations in extreme wind regimes.

The primary objective of this grant is to support a graduate student, Andy Hsu. He will pursue a Ph.D. degree with a focus on the process study of oceanic responses to tropical cyclones in the western Pacific observed during the ITOP intensive observation period using direct observations and numerical model simulations.

Surface wind stress is often computed using a drag coefficient (C_d). The parameterization of C_d is critical for studying the air–sea interaction. For example, the maximum potential intensity (MPI) of tropical cyclones is inversely proportional to C_d. Previous studies derive empirical formulas for C_d as a function of wind speed at 10-m from the sea surface (U_{10}). Because of the lack of in-situ observations, empirical expressions of C_d are limited to wind speeds less than 55 m s^{-1}. Recent studies suggest that C_d may also depend on surface gravity wave properties, which vary greatly in different sectors of

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tropical cyclones. It remains a challenge to parameterize C_d accurately. Further study on the parameterization of C_d is needed to improve predictions of tropical cyclones.

APPROACH

During the 2010 typhoon season (the intensive observation period of ITOP), two arrays of seven EM-APEX floats each were air-launched in front of typhoons Fanapi and Megi; the floats transmitted near-real time observations of velocity, temperature, salinity, and GPS position via Iridium satellite. The data from EM-APEX floats are used for the study of oceanic responses to Typhoons and to compute C_d. The PWP3D (Price et al. 1994) model is also used to facilitate the process study.

WORK COMPLETED

The graduate student, Andy Hsu, attended the ONR ITOP workshop in Taiwan in April 2012 and the AGU meeting in San Francisco in fall 2012, where he presented results from the EM-APEX float data. His past and ongoing work is on the data analysis of ITOP EM-APEX observations, estimates of C_d, and performing PWP3D model simulations.

RESULTS

Fourteen EM-APEX floats, seven Lagrangian floats, drifters, and dropsondes were deployed from C130 in front of typhoons Fanapi and Megi in the western Pacific during the ITOP experiment in 2010. Measurements of temperature, salinity, and velocity were taken by EM-APEX and Lagrangian floats. Wind data collected from dropsondes and velocity measurements from EM-APEX float are used to estimate C_d.

The C_d is estimated assuming the balance between the time rate change of the depth-integrated horizontal kinetic energy and the wind work. This assumption is justified using the PWP3D model simulation. Before the eye of tropical cyclone, the time rate change of depth integrated kinetic energy is balanced with the wind work (Fig. 1), and the momentum balance is linear, with negligible pressure gradient effect. Most of observed horizontal kinetic energy is within the upper 100 m. The available potential energy and kinetic energy from 100 to 200 m are negligible. This also justifies the method used by Sanford et al. (2011).

This method is applied to EM-APEX float measurements in typhoons Megi and Fanapi, and hurricanes Gustav, Ike, and Frances to compute C_d (Fig. 2). Significant results are summarized as follows.

- Estimates of C_d, computed from different tropical cyclones, peak at about 30 m s^{-1} wind speed, and decrease at higher wind speed. This feature was reported by Powell et al. (2003).
- Estimates of C_d, computed in Typhoon Megi, are nearly constant between 50 and 65 m s^{-1} wind speed, which is surprisingly in agreement with the value reported by Powell et al. (2003) extending to higher wind speeds.
- The estimate of C_d computed in Typhoon Megi at 30 m s^{-1} wind speed is about a factor of 2–3 greater than those computed from other tropical cyclones. The value is similar to that of the Powell (2007) C_d computed to the left of a tropical cyclone, although our estimates of C_d in Typhoon Megi are computed to the cyclone's right.

IMPACT/APPLICATION

Tropical cyclones cause strong oceanic responses, e.g., surface waves, inertial waves, and a deepening of the surface mixed layer. To improve the modeling skill of oceanic responses to tropical cyclones and the prediction of tropical cyclones, we need to understand the small-scale processes responsible for the air–sea fluxes and interior oceanic mixing, and the meso-scale oceanic processes that modulate the background oceanic heat content. The ITOP field experiment provides direct observations of oceanic responses forced by tropical cyclones and the ocean's recovery, as well as aid understanding of the dynamics of small- and meso-scale oceanic processes. These observations will help improve the prediction skill of oceanic and atmospheric models in high wind regimes.

RELATED PROJECTS

<u>Studying the Origin of the Kuroshio with an Array of ADCP-CTD Moorings (N00014-10-1-0397) as a part of the OKMC DRI</u>: The primary objectives of this observational program are to quantify the origin of the Kuroshio, to quantify its properties at the origin and as it evolves downstream, and to study the effects of mesoscale eddies on Kuroshio transport. Kuroshio transport off Luzon is computed using direct velocity measurements from a moored array. The annual mean transport is 15 Sv. Large variations of >10 Sv within 10s of days are caused by westward propagating eddies interacting with the Kuroshio.

PUBLICATIONS (wholly or in part supported by this grant)

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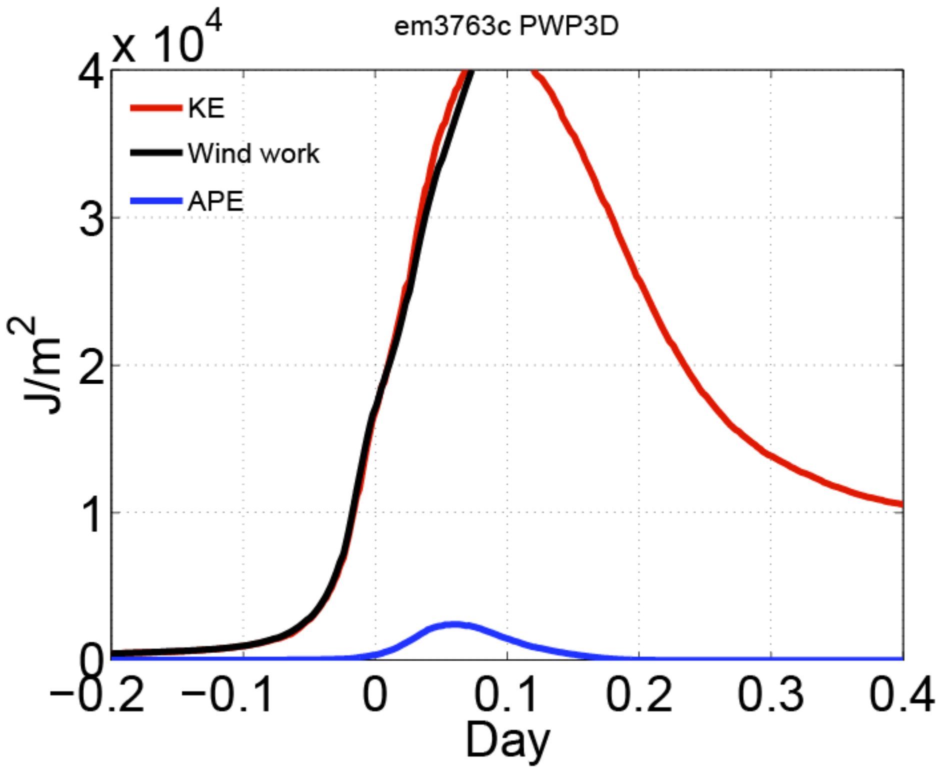

Figure 1. PWP3d model results of wind work (black curve), horizontal kinetic energy (red curve) and potential energy (blue curve) integrated in the upper 200 m at the position of EMAPEX float 3763C under Typhoon Megi. The time is referenced to the typhoon's eye.

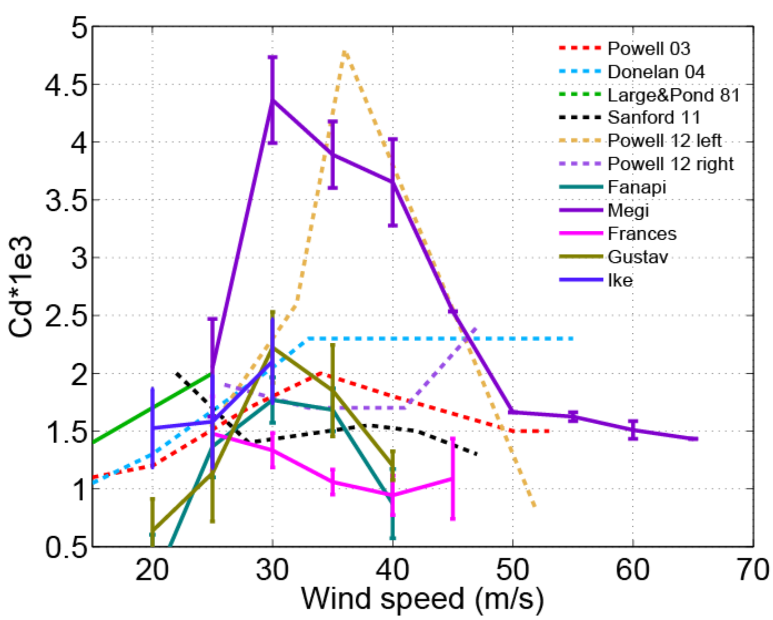

Figure 2. Estimates of drag coefficient C_d in previous studies (dashed curves) and those in the present study (solid curves).

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